Spatial and Temporal Heterogeneity of Redox Fluctuation and Microbial Communities in a Tropical Soil

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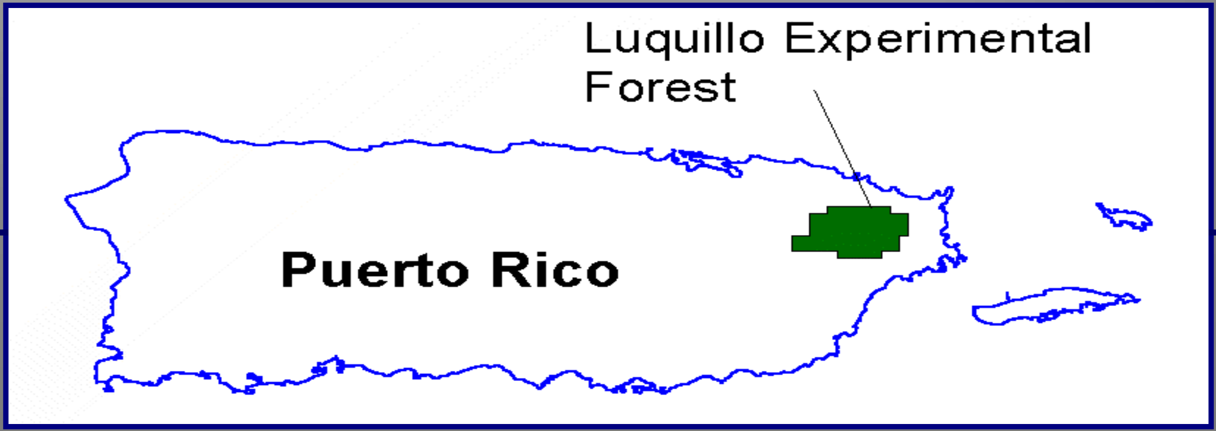
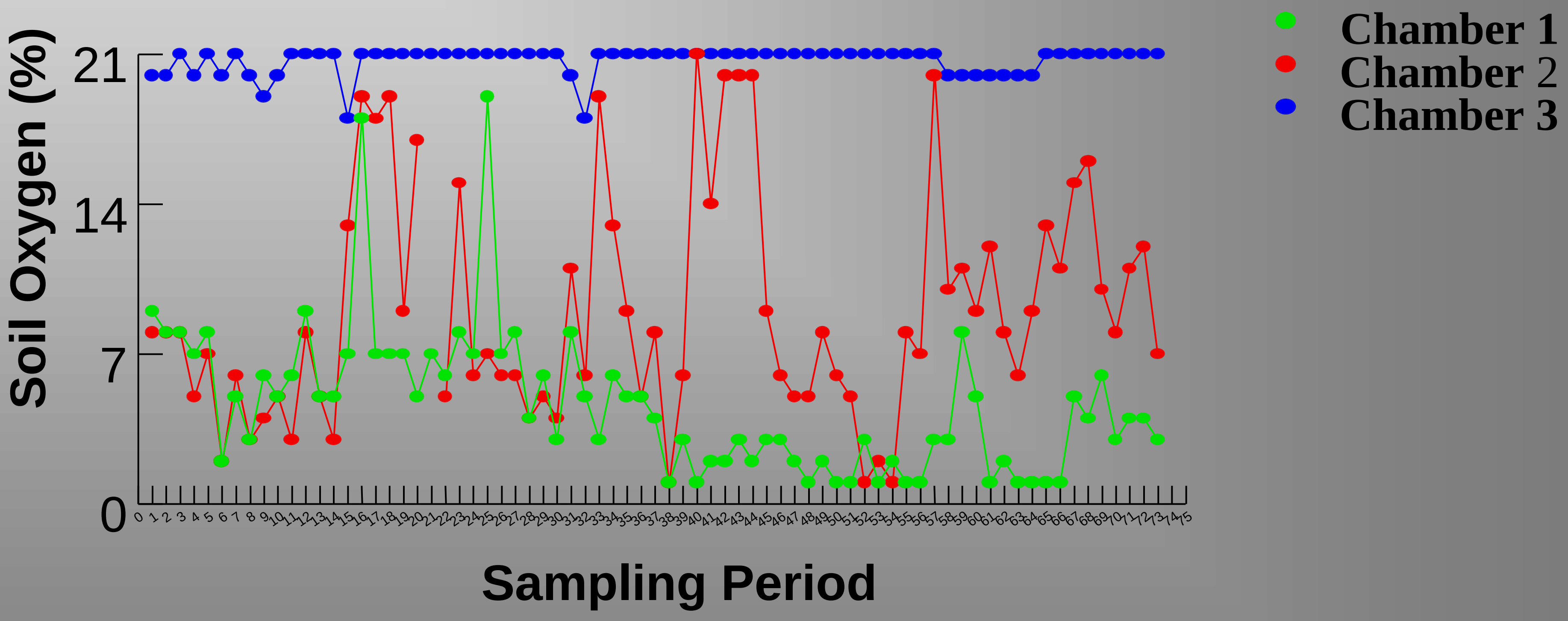
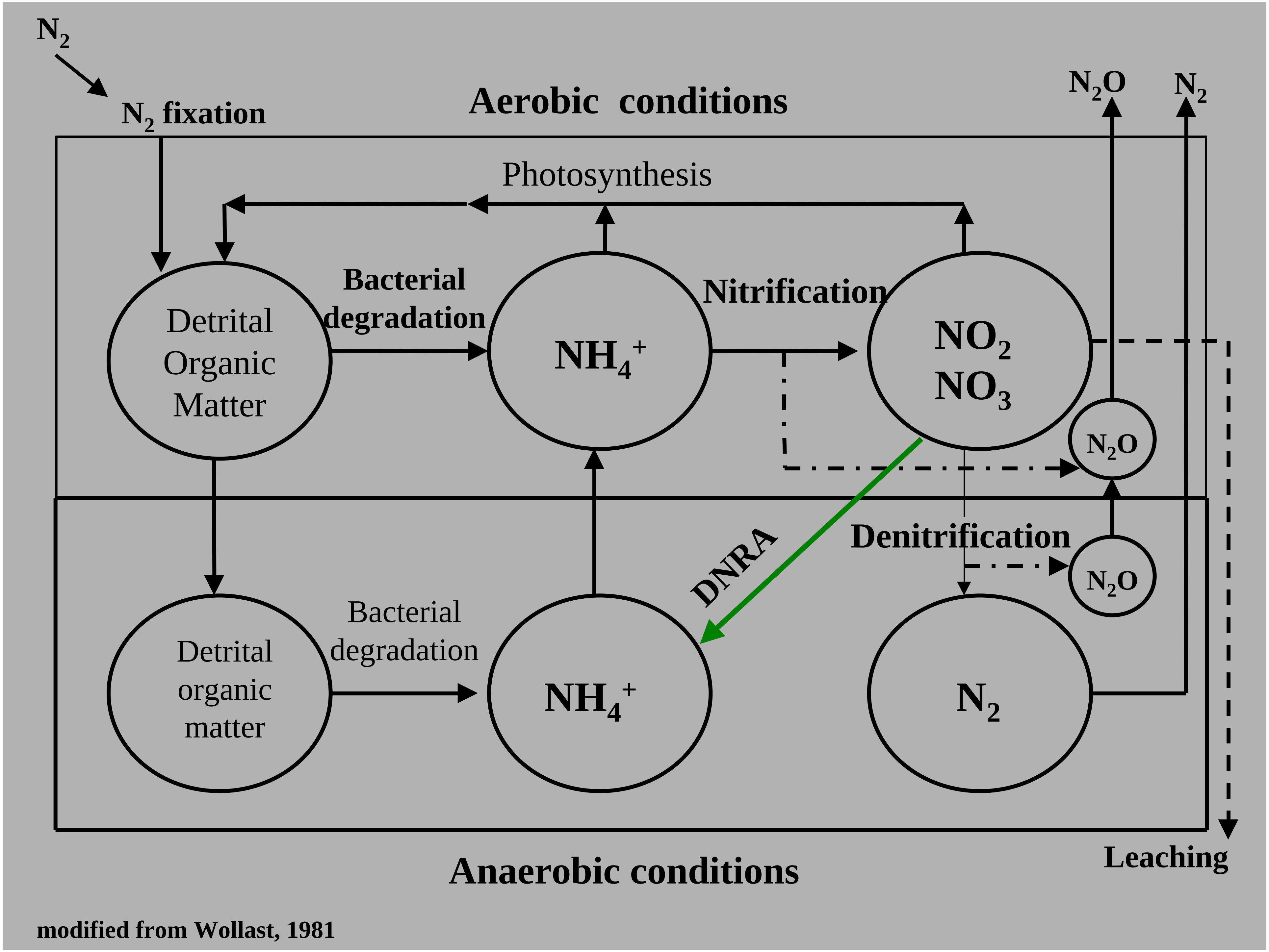
Luquillo Experimental Forest, Puerto Rico



Soil O_2 in Palo Colorado Forest, Puerto Rico



From: Silver et al. 1999



N_2
N_2 fixation
Aerobic conditions
N_2O
N_2
Photosynthesis
Detrital Organic Matter
Bacterial degradation
NH_4^+
Nitrification
NO_2 NO_3
N_2O
DNRA
Denitrification
N_2O
Detrital organic matter
Bacterial degradation
NH_4^+
N_2
Leaching
Anaerobic conditions
modified from Wollast, 1981

The “Biologically Relevant” Redox Ladder

Mineralization & Nitrification

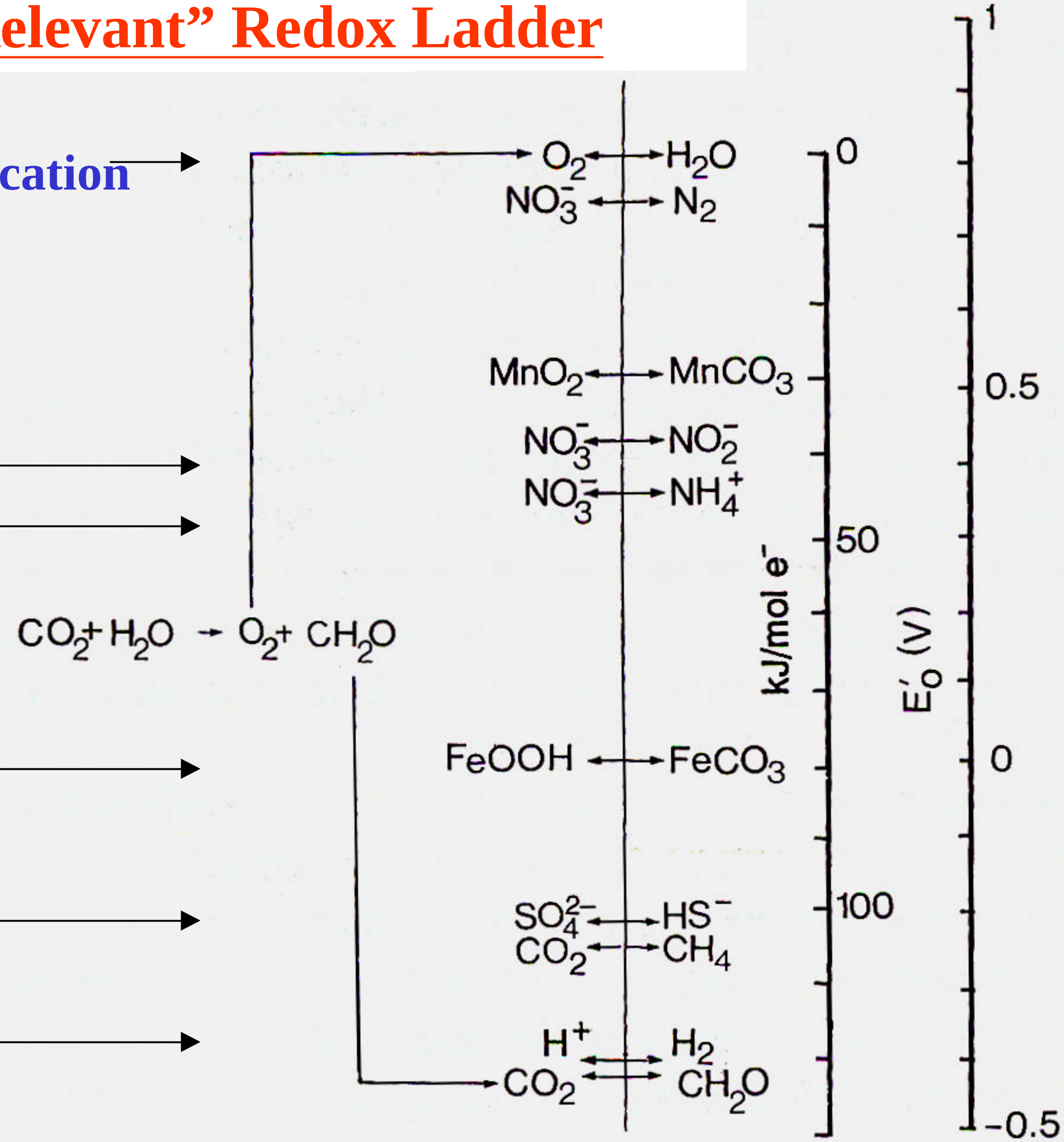
Denitrification

DNRA

Iron reduction

Sulfate reduction

Methanogenesis

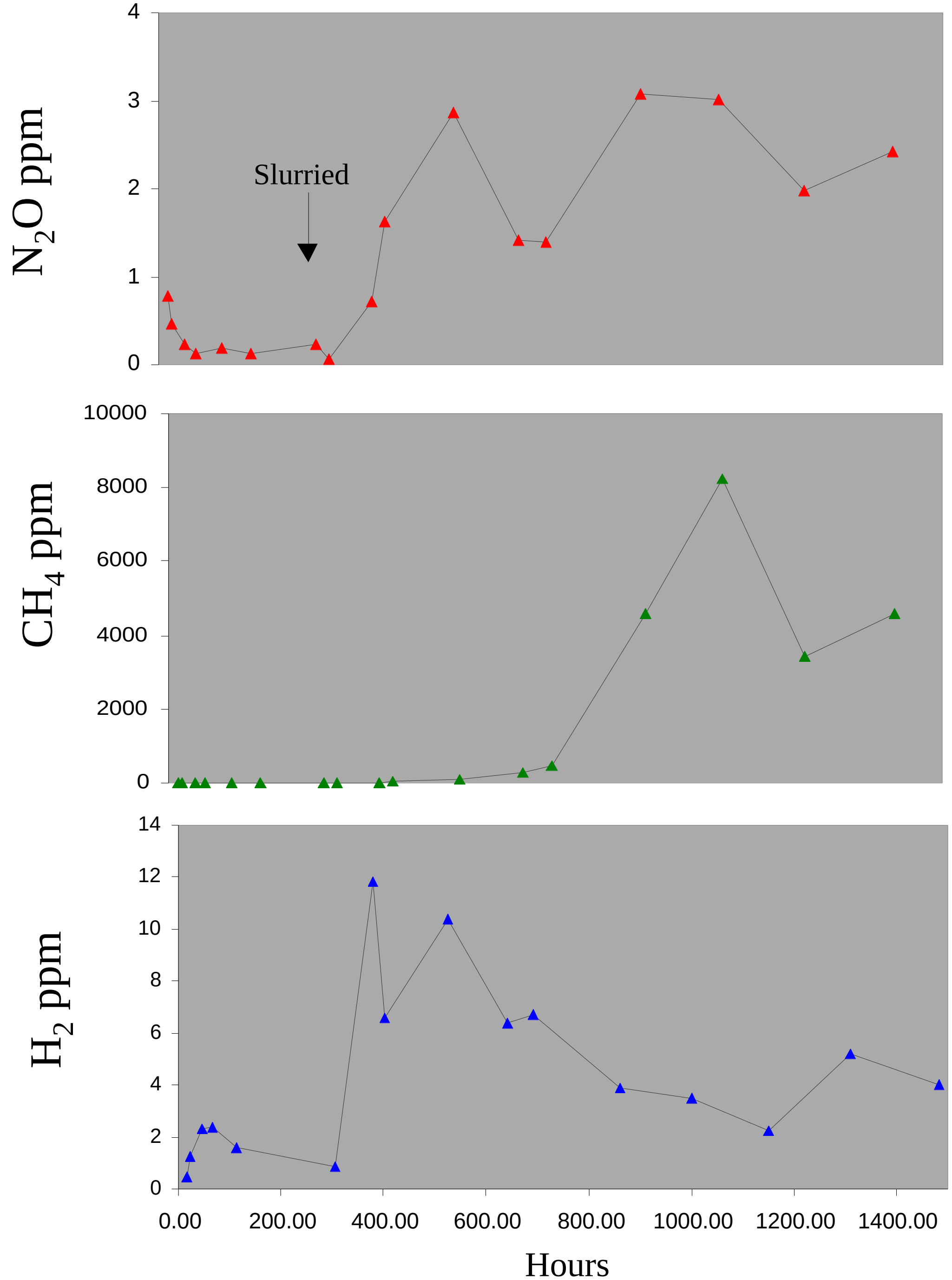


Questions:

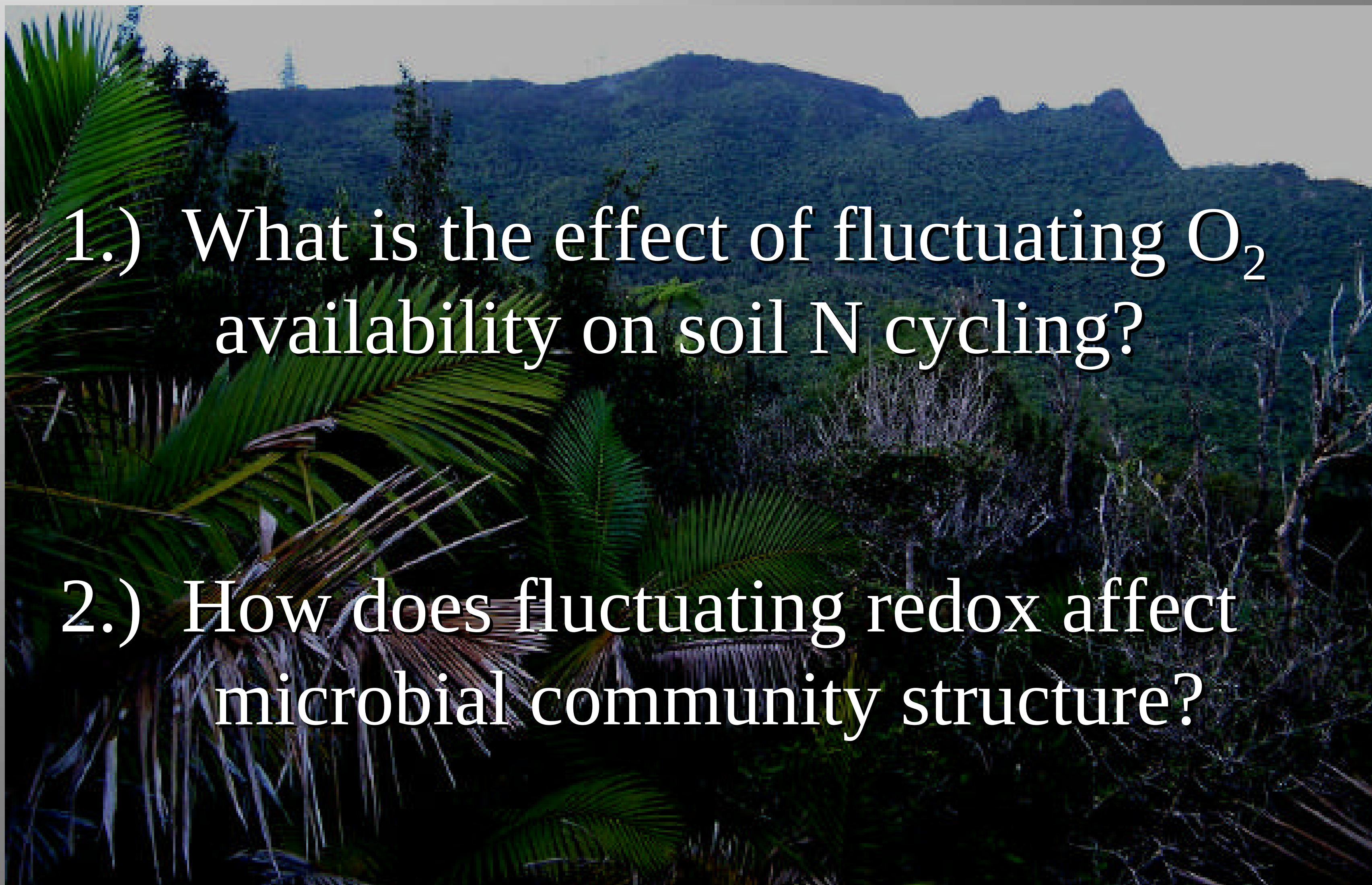
1.) What is the characteristic time-scale of O_2 fluctuation and redox shifts?

2.) Can H_2 concentrations be used as a biologically relevant proxy for pE measurements?

Lab Incubations and Trace Gas Measurements



Research Questions:



1.) What is the effect of fluctuating O_2 availability on soil N cycling?

2.) How does fluctuating redox affect microbial community structure?

Redox Fluctuation Experiment:

- Treatments:

  1.) constant O_2

  2.) alternating O_2/N_2 -12 hours

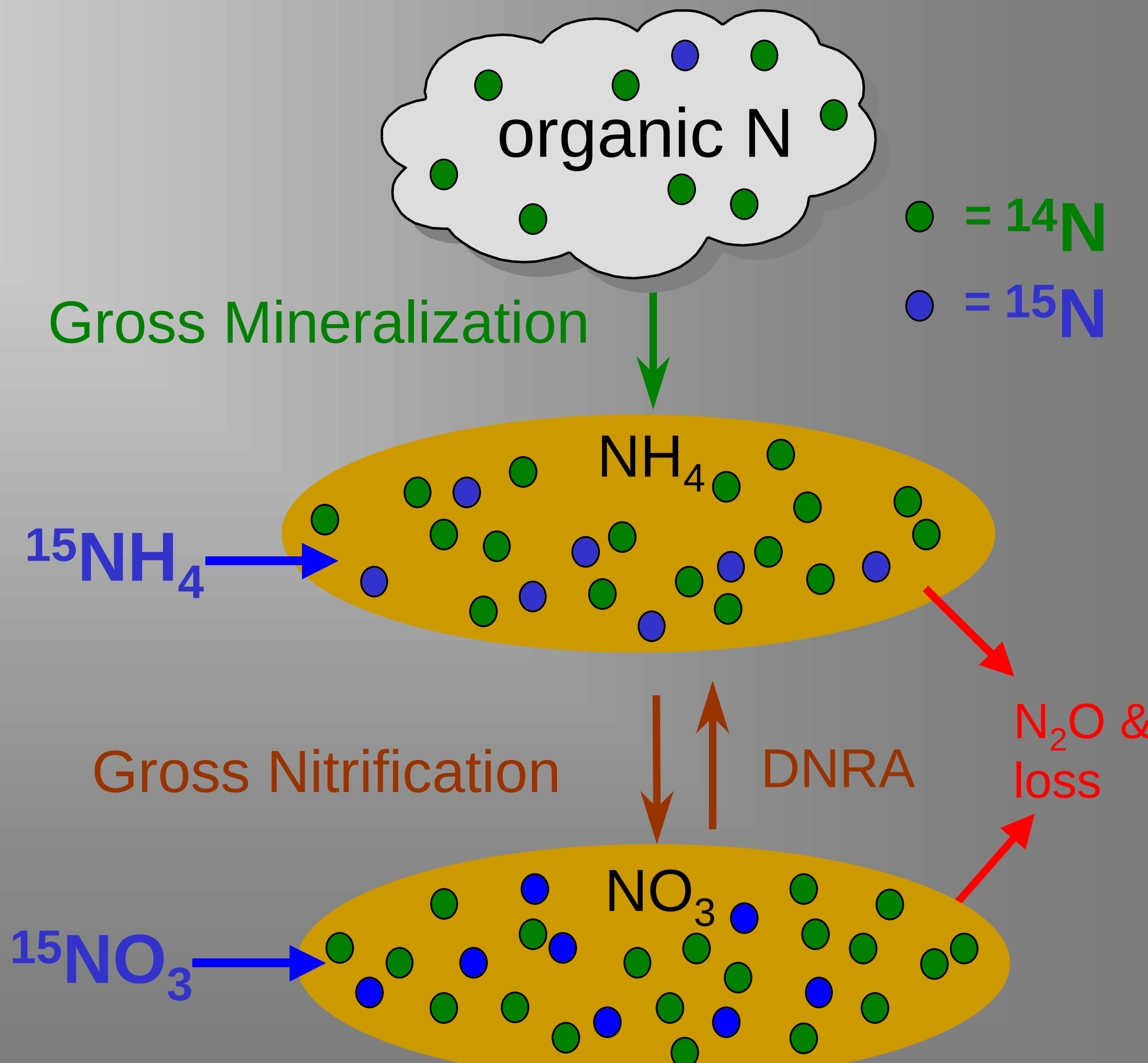
  3.) alternating O_2/N_2 -4 days

  4.) constant N_2

- Harvest points: initial, 3 wk, 6 wk

- Aerobic ^{15}N tracer experiment ($^{15}NO_3$ & $^{15}NH_4$) for each harvest

^{15}N Pool Dilution & Tracer Method



modified from Christine Hawkes 2003

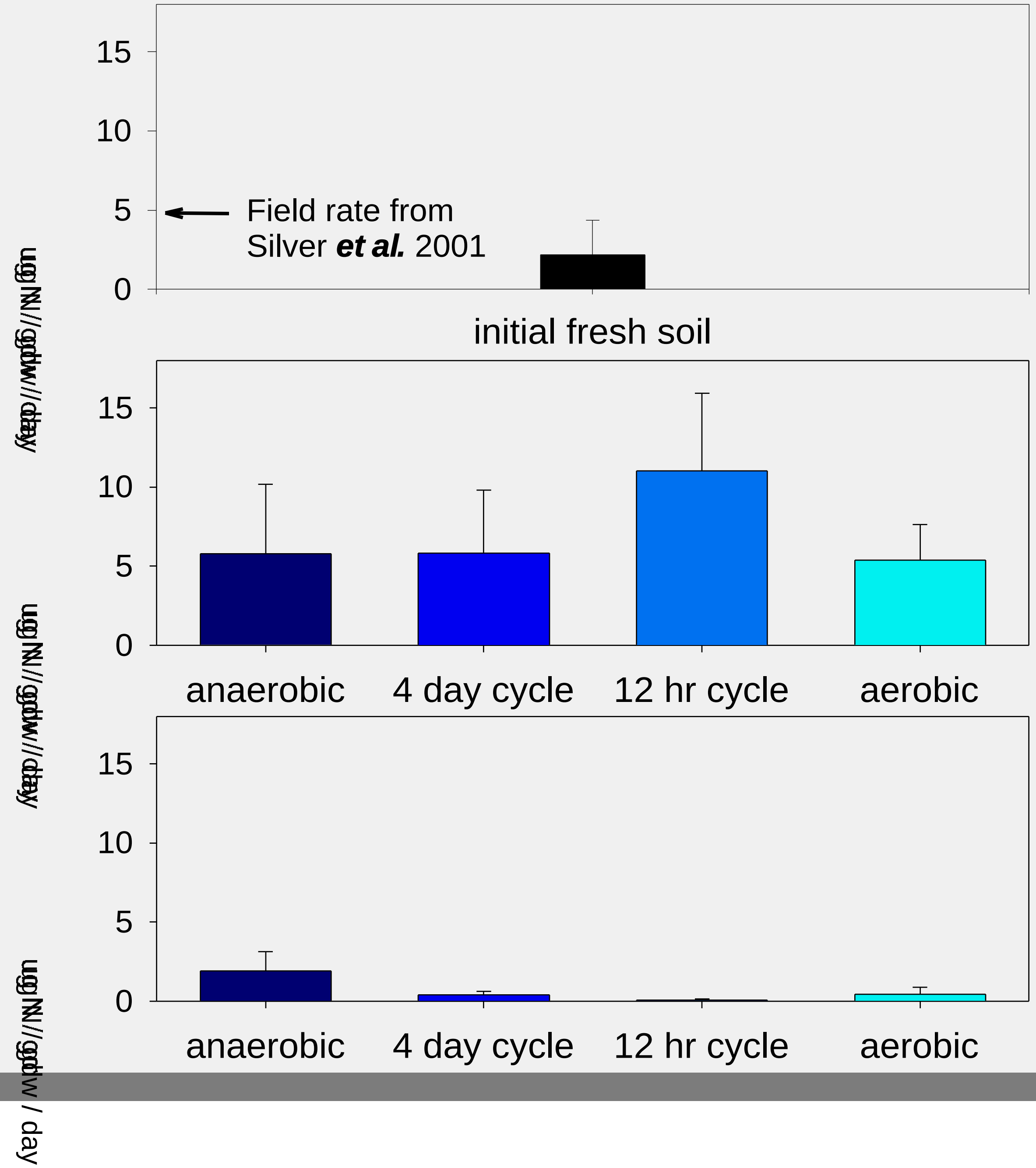
Gross Mineralization in 0-3 hrs

Experiment Timeline

Start

3 weeks

6 weeks



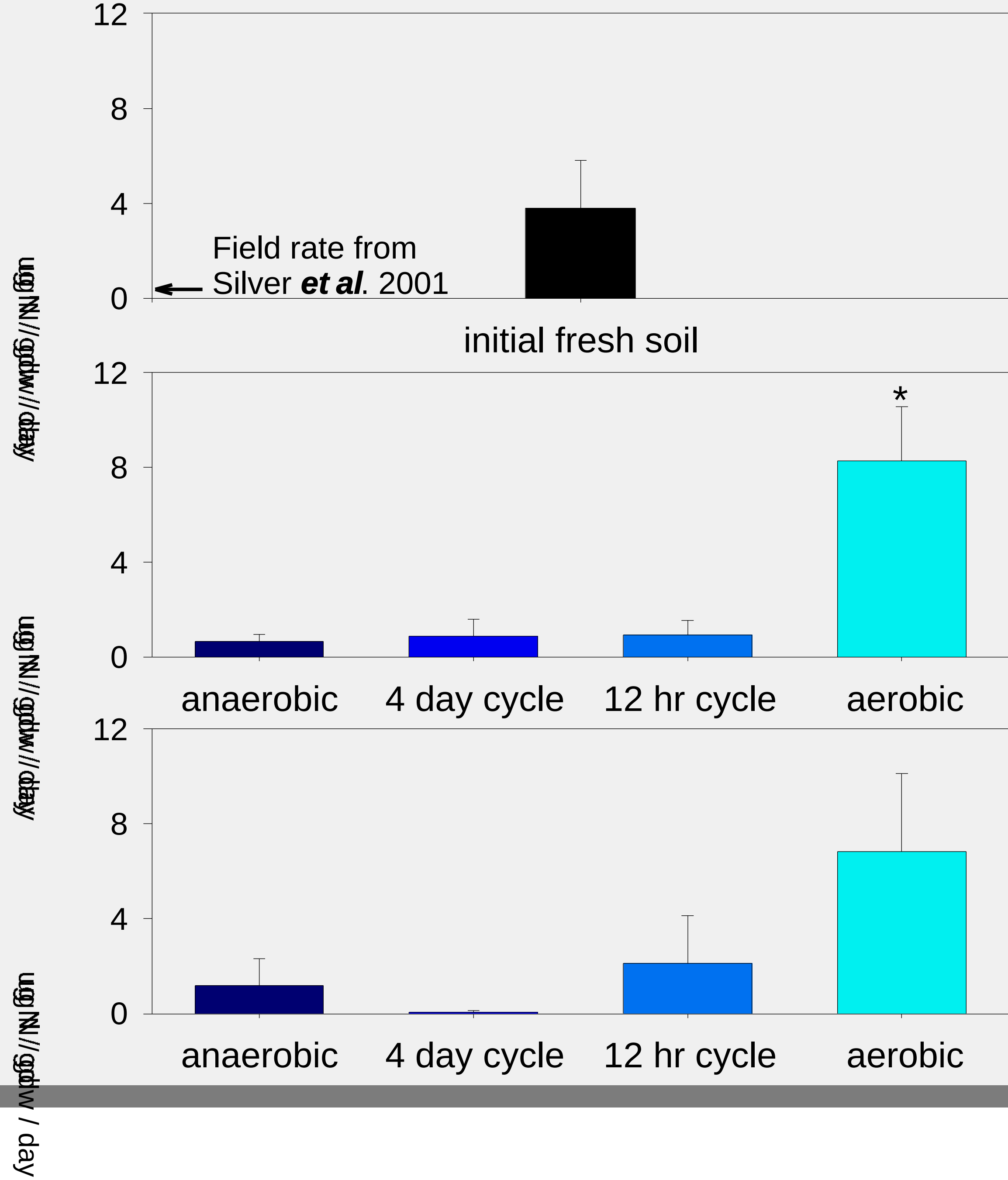
Gross Nitrification in 0-3 hrs

Experiment Timeline

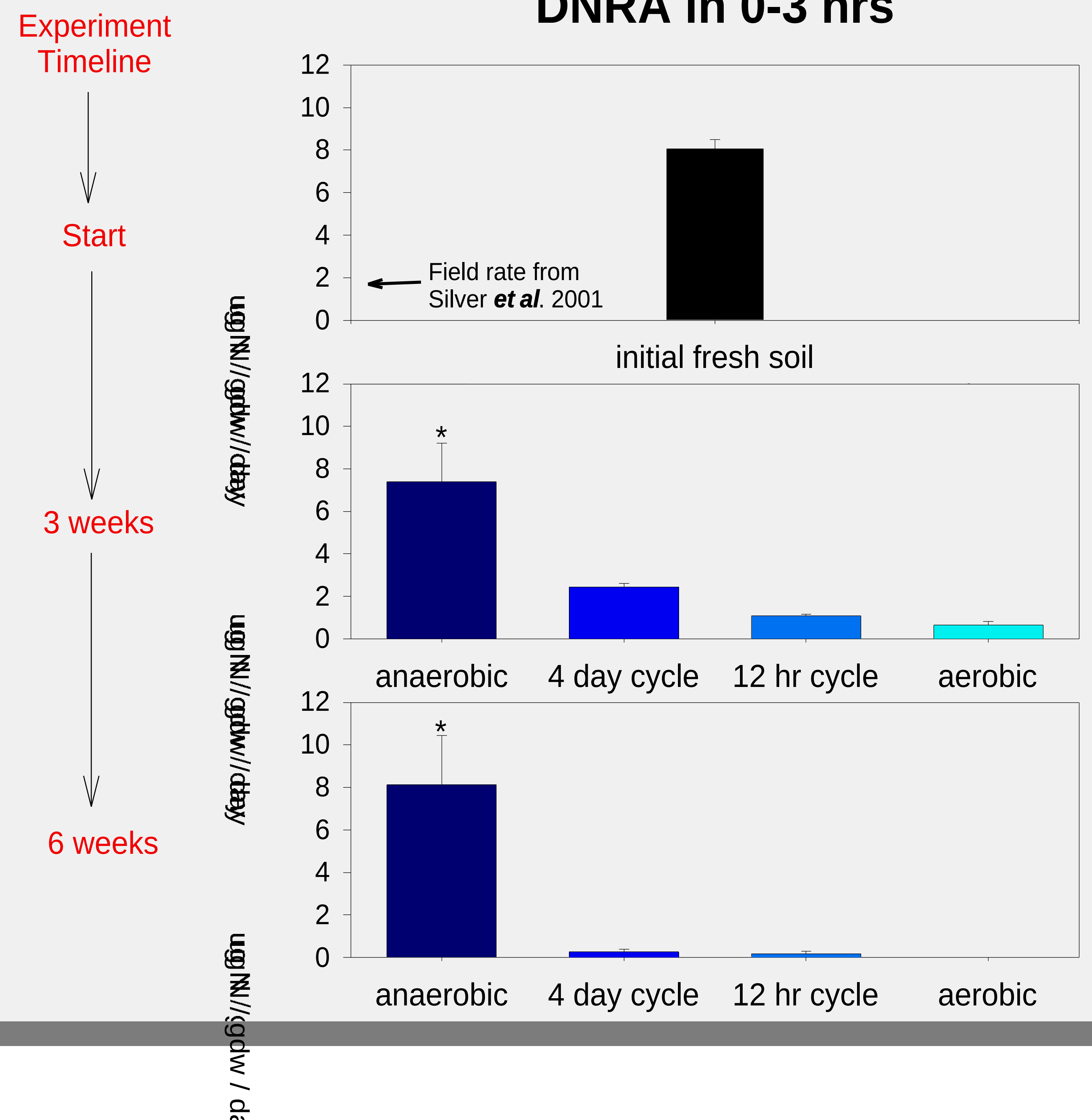
Start

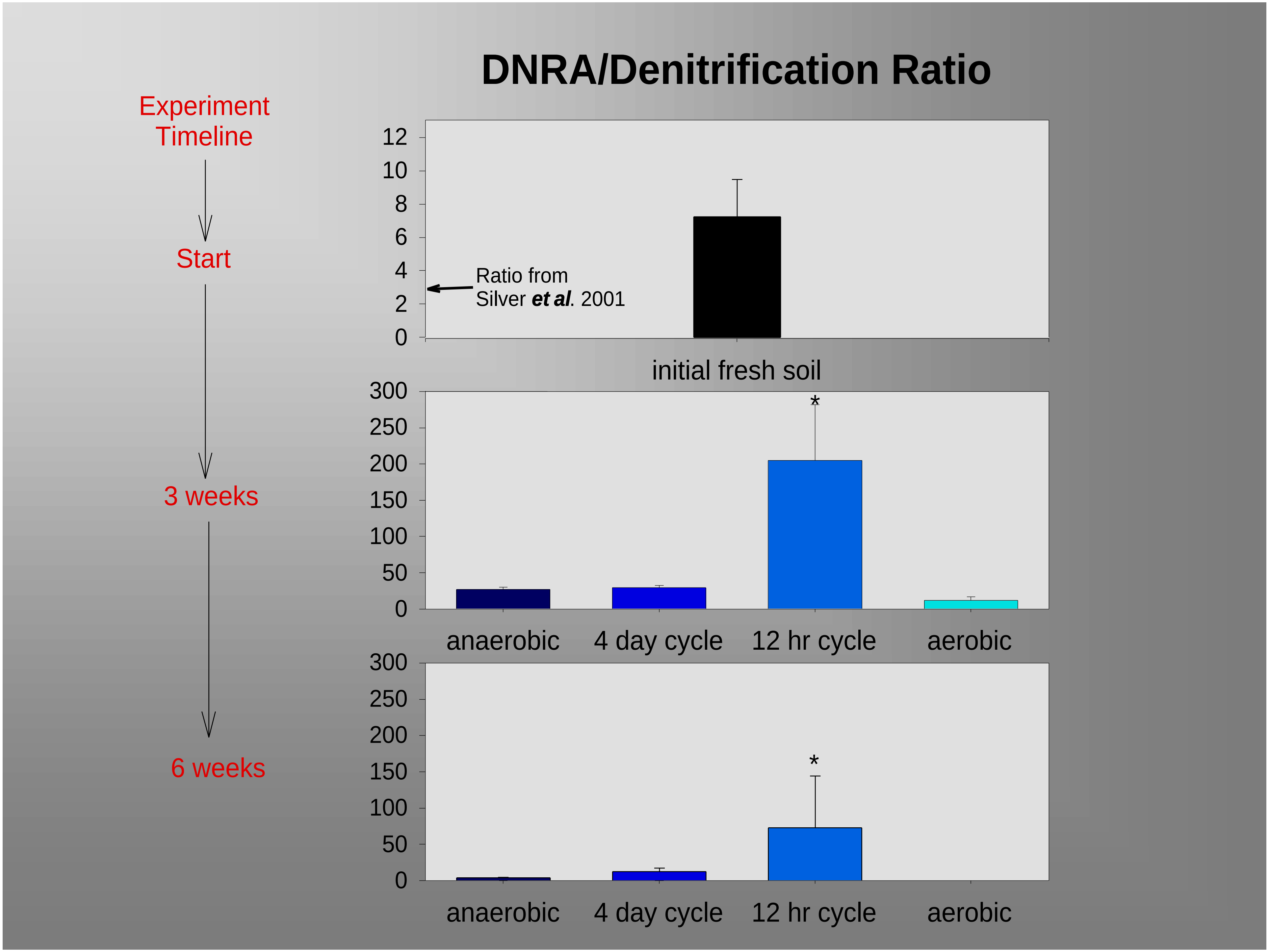
3 weeks

6 weeks



DNRA in 0-3 hrs





DNRA/Denitrification Ratio
Experiment Timeline
Start
3 weeks
6 weeks
Ratio from Silver et al. 2001
initial fresh soil
anaerobic
4 day cycle
12 hr cycle
aerobic
*
0
2
4
6
8
10
12
50
100
150
200
250
300

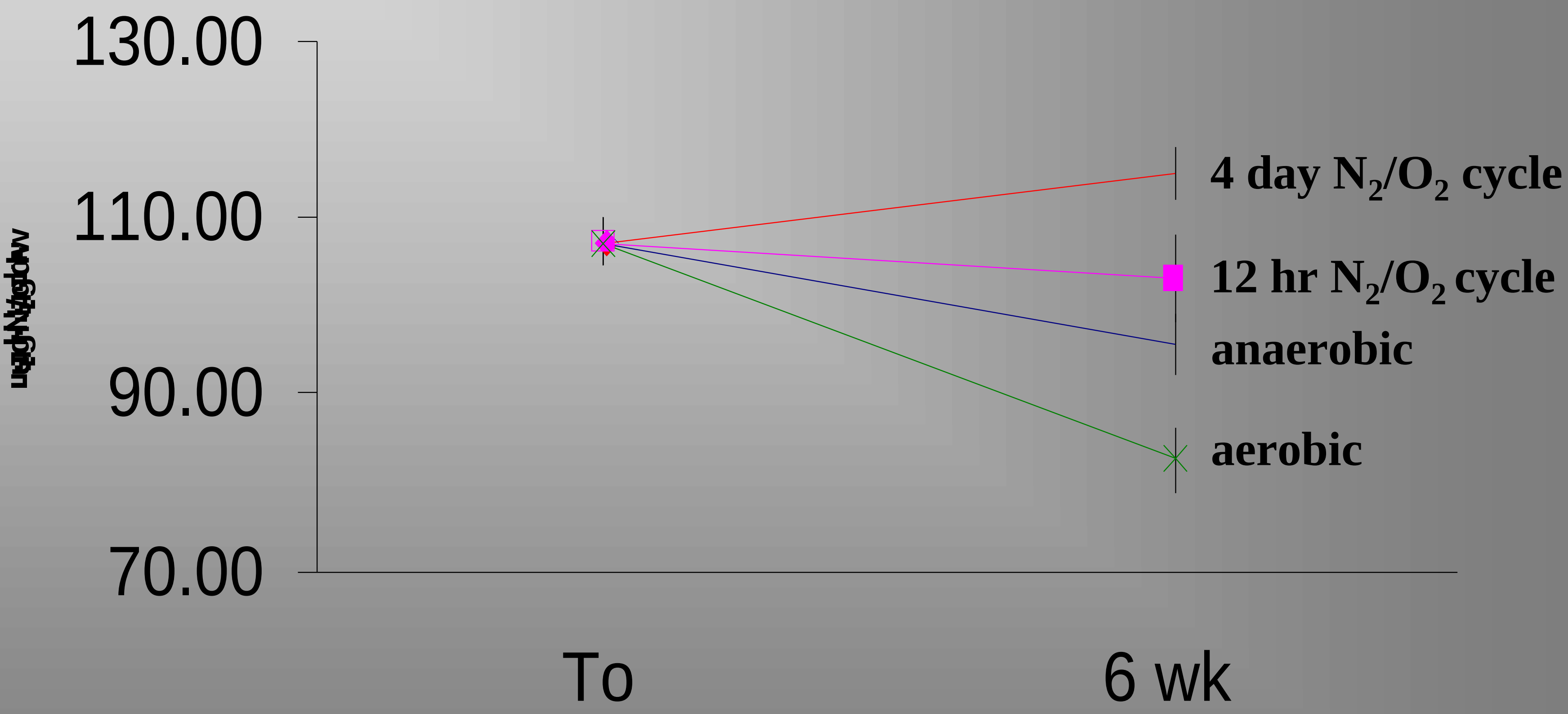
Results Summary -N cycling

- Gross mineralization is relatively insensitive to O_2 availability.

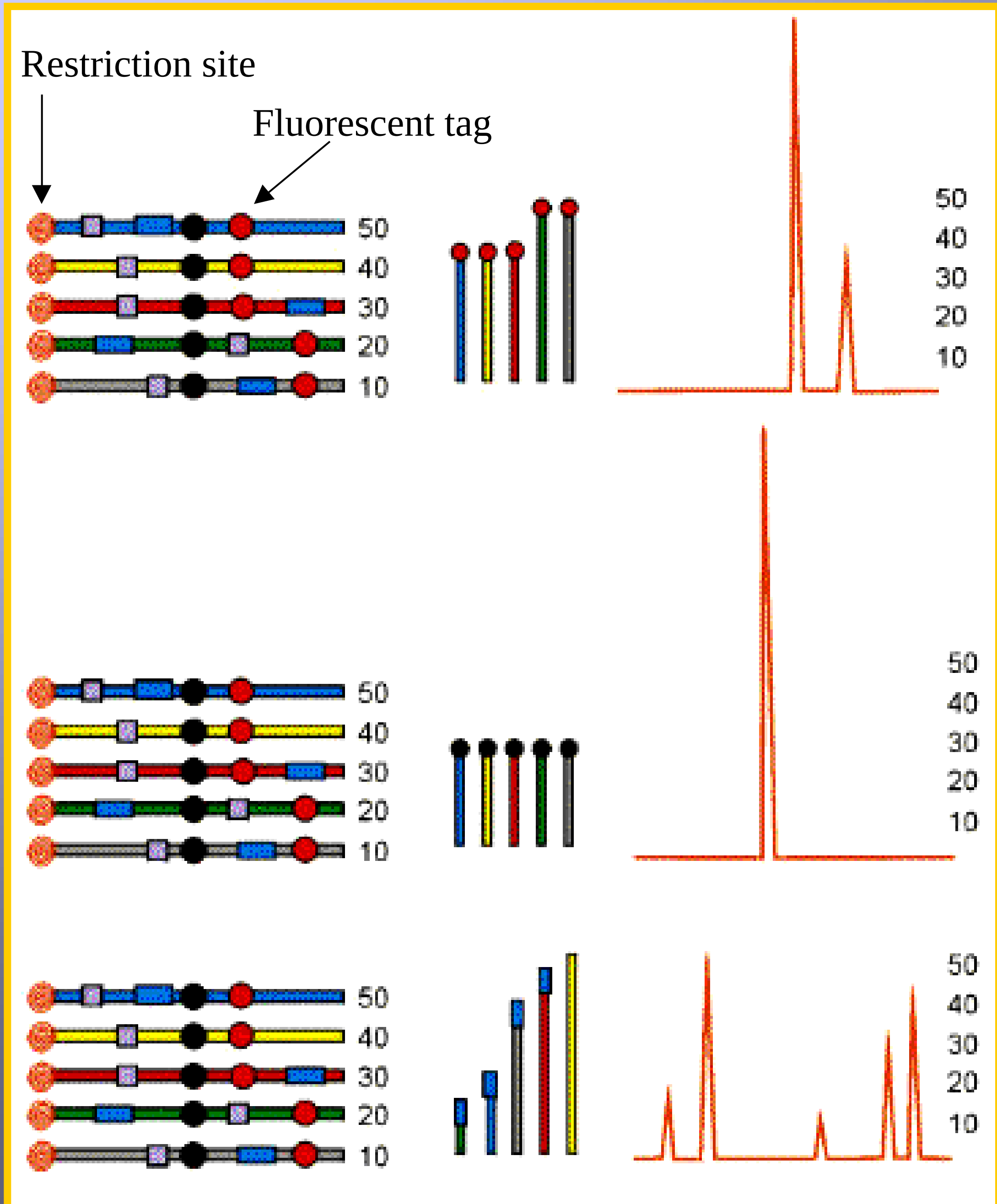
- Gross nitrification is very sensitive to low redox conditions, yet occurs when O_2 becomes available.

- DNRA is a significant fate for NO_3 and is promoted by low and fluctuating redox conditions. It is unaffected by brief O_2 exposure.

Microbial Biomass N:



T-RFLP Data

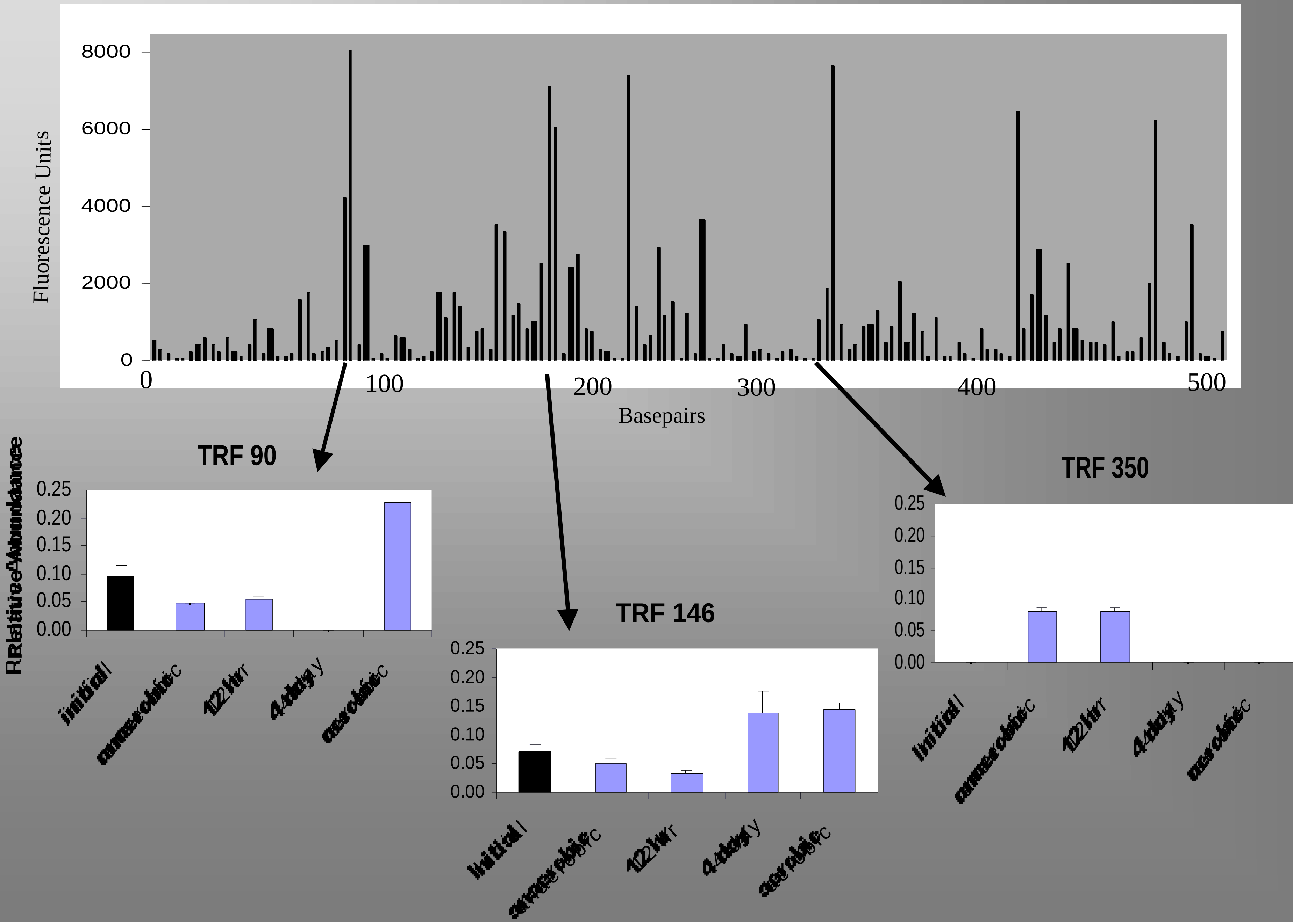


2 fragment lengths =
2 different ‘species’

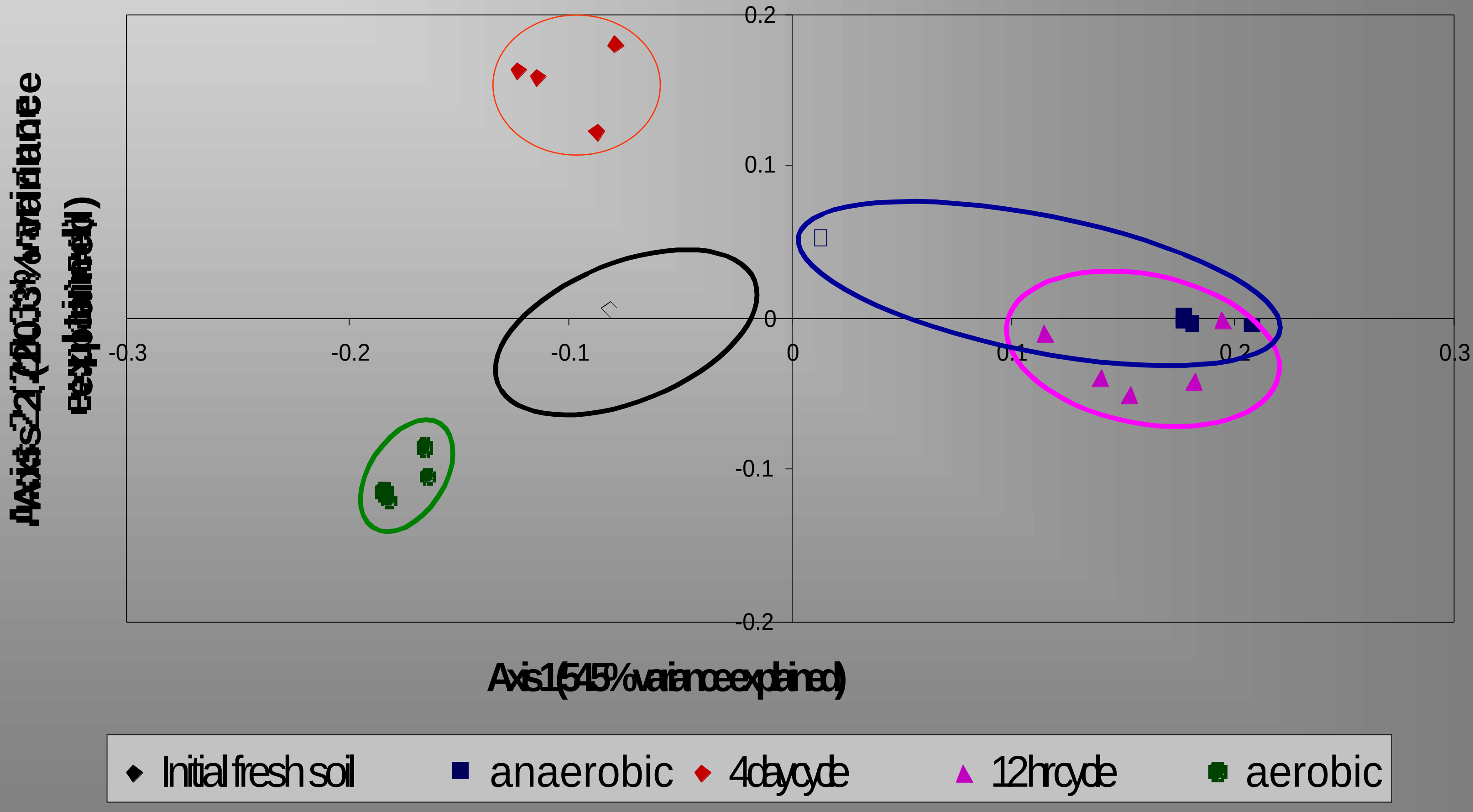
1 fragment =
1 abundant ‘species’

5 fragment lengths =
several different ‘species’

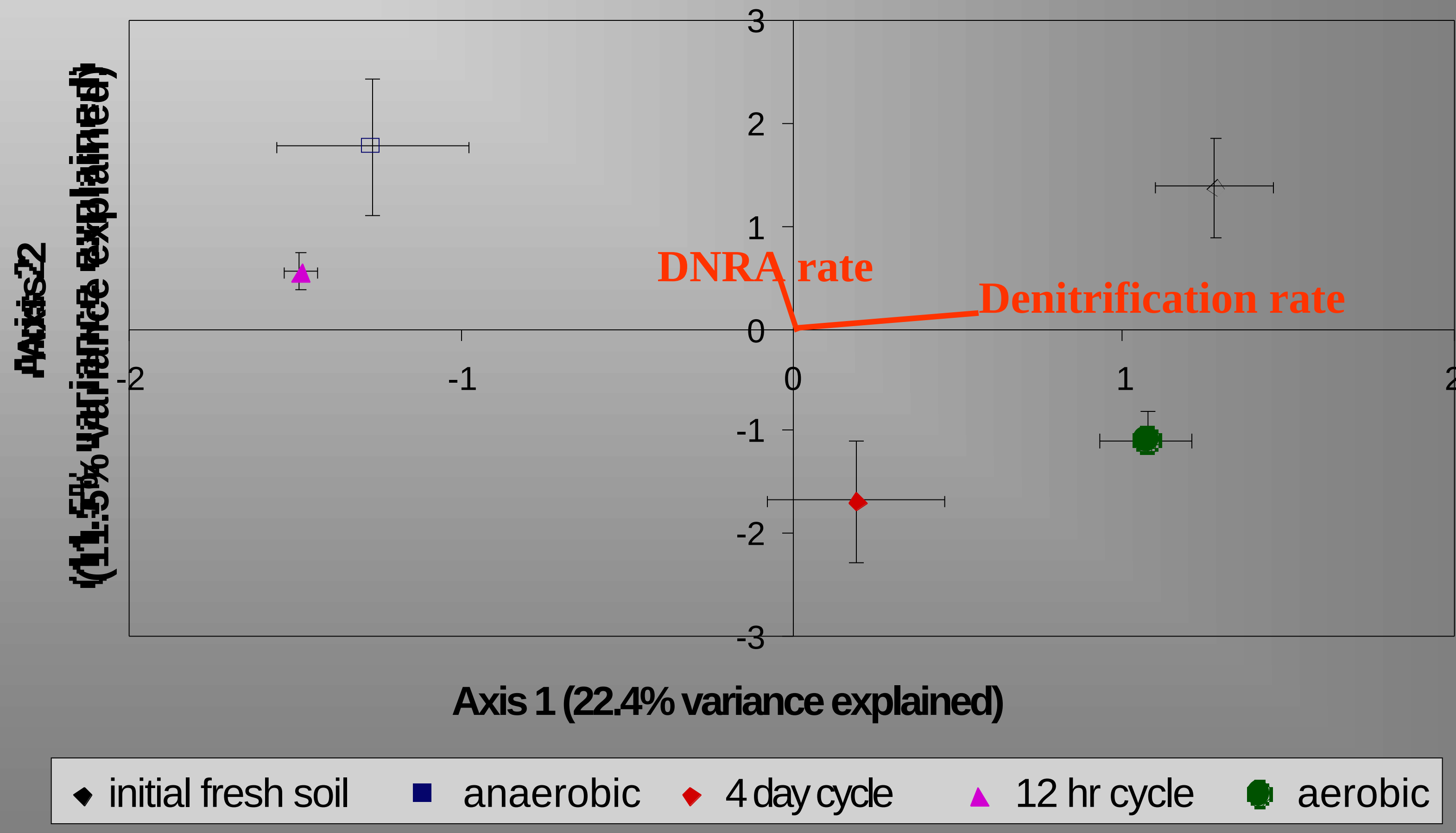
Initial Soil Community TRF Profile



T-RFLP Principal Components Analysis



Canonical Correspondence Analysis (Bacterial community & N-cycling rates)



Results Summary -Bacterial Communities

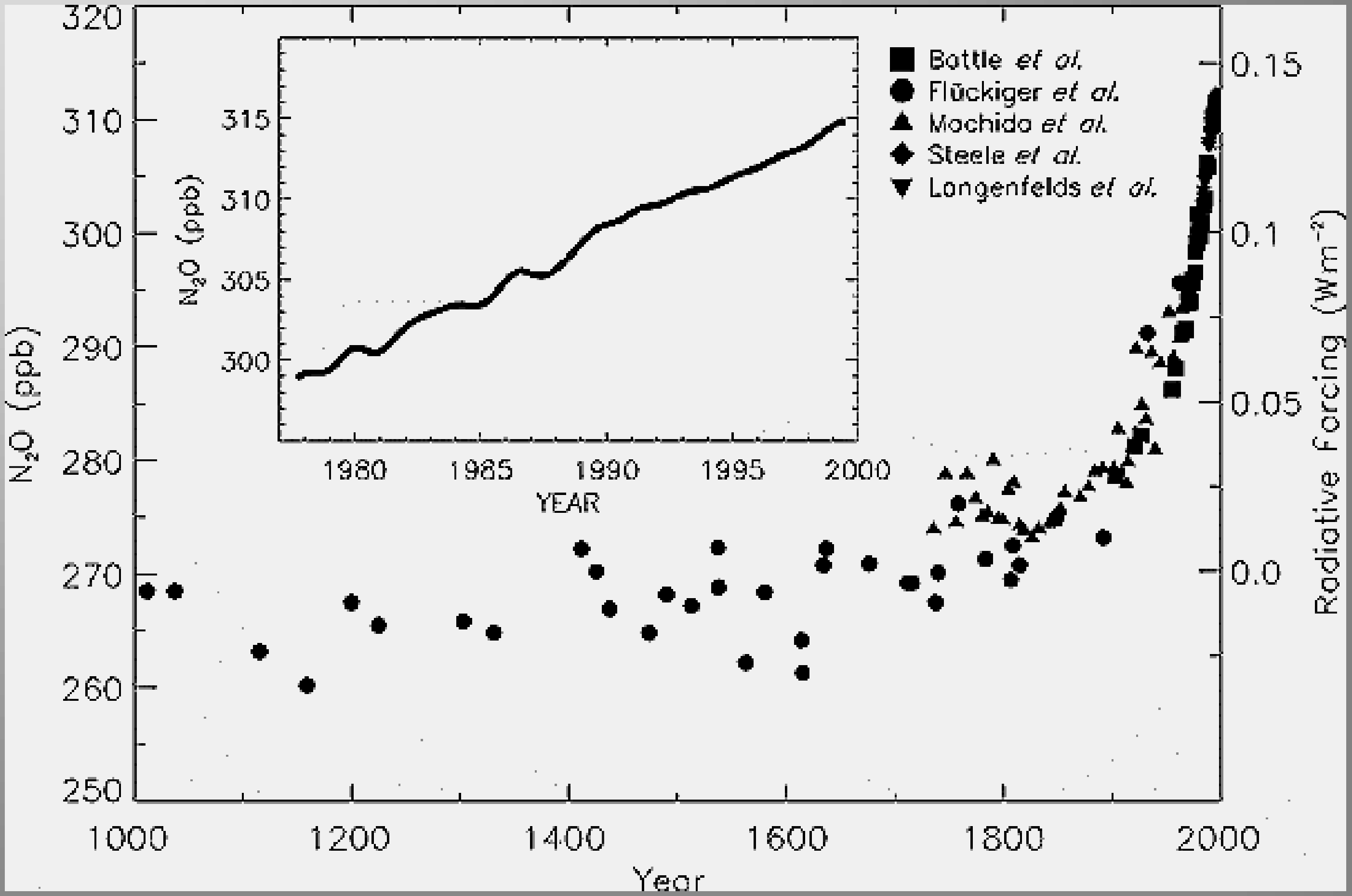
- Microbial biomass is maintained by redox fluctuations and diminished by static oxic or anoxic regimes.

- Field communities are best approximated by lab-incubated communities from a 4-day fluctuation regime.

- Microbes adapted to both oxic and anoxic conditions appear to be rare in these soils.

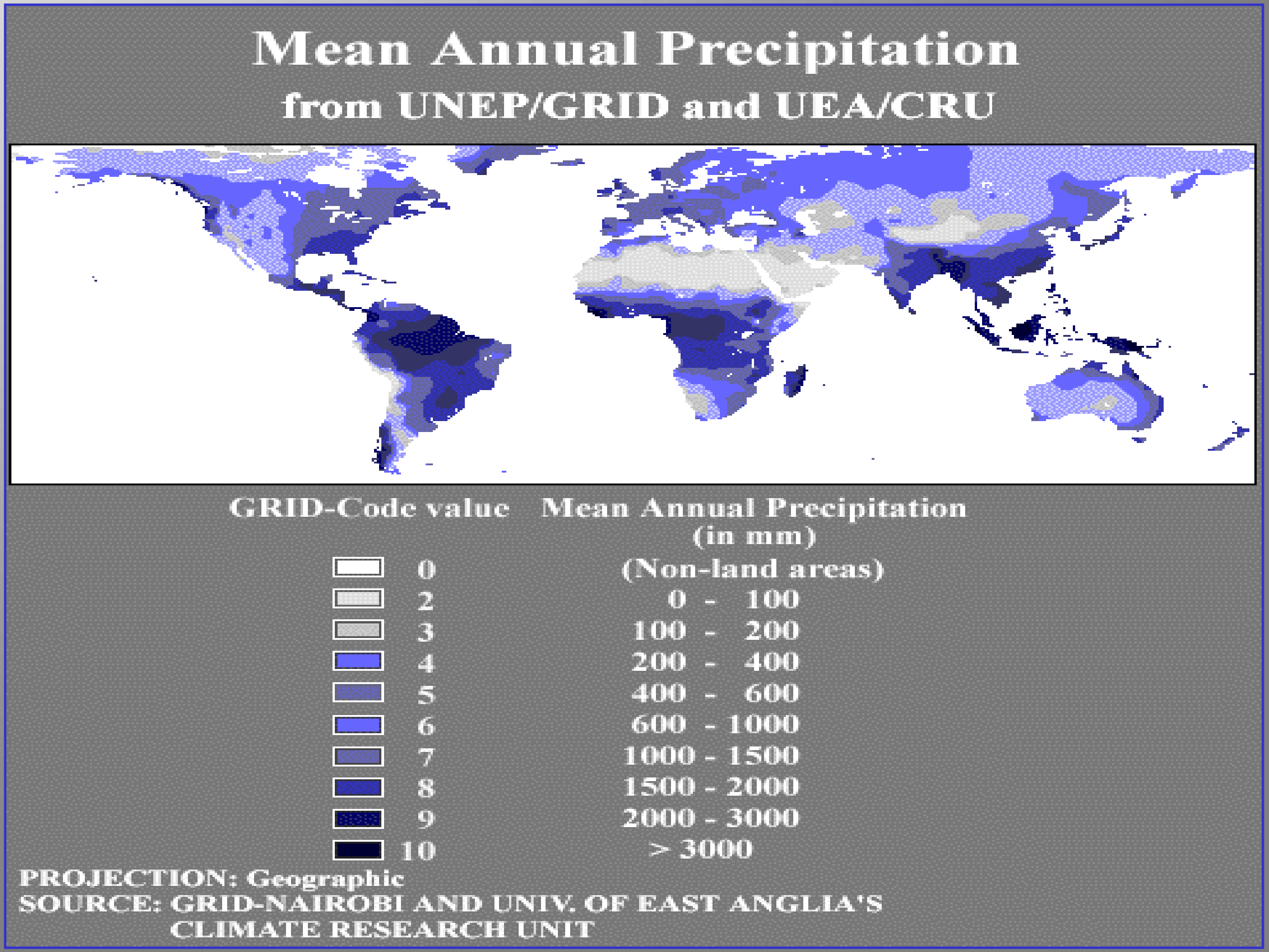
- Denitrification is particularly sensitive to microbial community composition.

Ice core and measurement record of global N_2O Trend



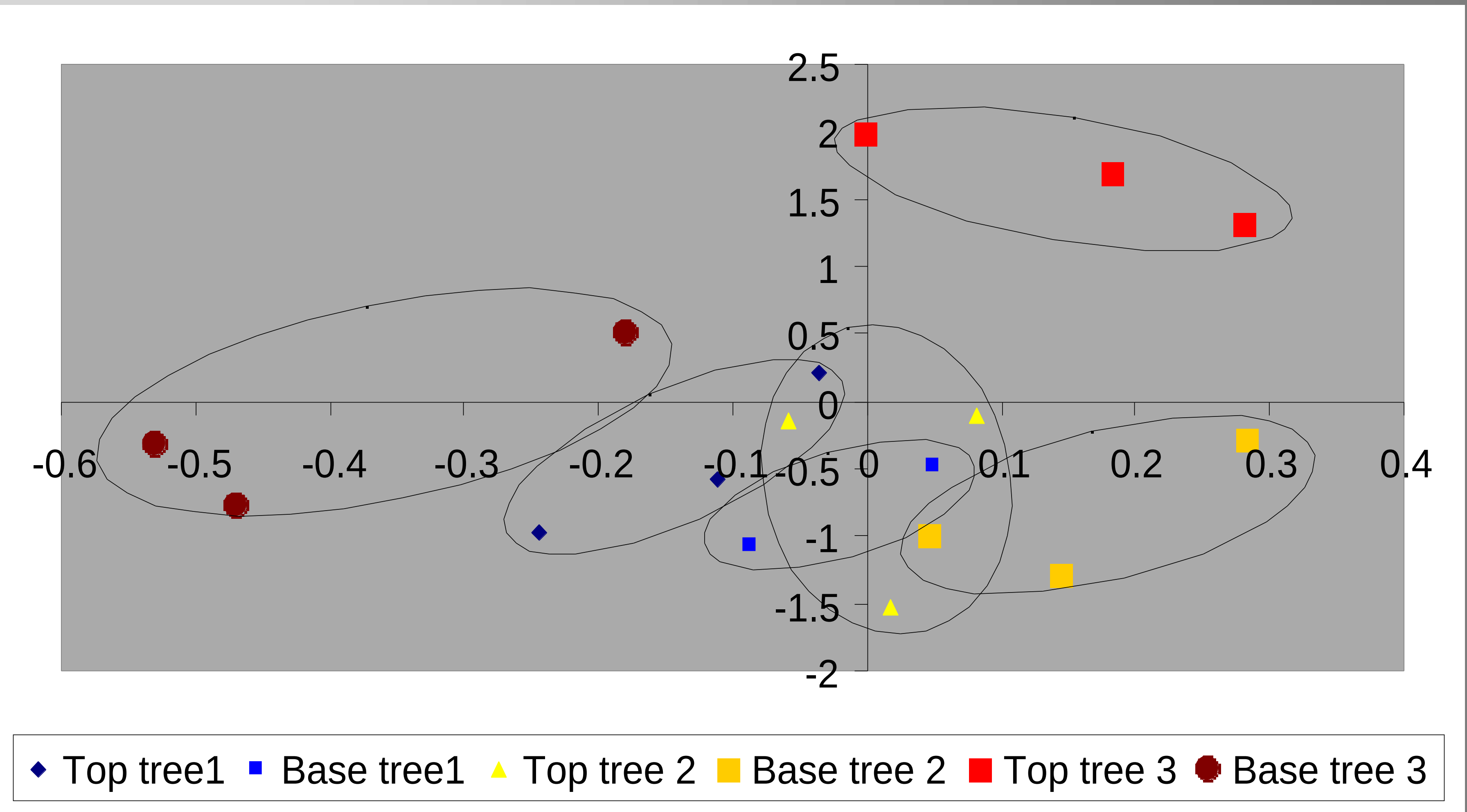
From IPCC 2001 (3rd Assessment Report) Change in N_2O abundance for the last 1,000 years as determined from ice cores and whole air samples.

The Top-Down Approach



The Bottom-Up Approach

Spatial heterogeneity in Colorado forest soil
NMS plot of bacterial T-RFLP



Conclusions

• *N Conservative*

Redox fluctuation in tropical soils may encourage N retention through the co-occurrence of nitrification and rapid DNRA.

• *Flexible Communities*

Microbes that process N in variable redox soils may be more tolerant of redox shifts than commonly thought possible.

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